Response of rate-and-state faults to quasi-static stress perturbations

Nadia Lapusta
Department of Mechanical & Civil Engineering and Seismological Laboratory
California Institute of Technology

Faults respond to stress perturbations with changes in seismicity. One classic example of such response is aftershock sequences that follow large earthquakes and have decay with time well described by empirical Omori's law. Another example is non-trivial period-dependent response to periodic stress perturbations in Nepal, where seismicity shows significant variations due to annual monsoon-induced stress variations but not to semidiurnal tidal stresses of the same magnitude.

Dieterich (Tectonophysics, 1994) derived equations for seismicity rate changes on rate-and-state faults in response to quasi-static stress perturbation using simplifying assumptions about earthquake nucleation, including a one-degree-of-freedom spring-slider system to represent elastic interactions. This spring-slider rate-and-state model (SRM) can reproduce the Omori's law in response to a static stress step, but not the observed response of seismicity to periodic stress perturbations in Nepal.

We show that the seismicity response of continuum rate-and-state models (CRM), in which a finite rate-and-state fault is embedded in an elastic medium, can be qualitatively and quantitatively different from the SRM predictions. The two models, SRM and CRM, exhibit qualitatively similar seismicity behaviors in some simple cases, e.g. when nucleation sites in CRM are located in the middle of rate-weakening regions and have nearly uniform properties. However, the response is qualitatively different for nucleation sites with significantly heterogeneous properties or those located close to the boundary between the locked and creeping regions; this is because, in such cases, time evolution of the nucleation process is significantly different from the one approximated by the SRM (Kaneko and Lapusta, JGR, 2008). We find that the continuum rate-and-state models can reproduce the period-dependent seismicity response in Nepal for plausible sets of rate-and-state parameters (Ader, Lapusta, Avoauc, and Ampuero, GJI, 2014). Our studies also indicate that the quantity $a\sigma$, where a is a rate-and-state parameter and σ is the effective normal stress, can be substantially underestimated based on the SRM.

Time-permitting, we will also discuss rate-and-state models of small repeating earthquakes that show that repeating earthquake sequences interact predominantly through stress changes due to postseismic slip (Lui and Lapusta, 2016).